Asynchronous Stimulation for Cochlear Implants

Tom Zajdel

May 8, 2012

Ohio State University
Department of Electrical & Computer Engineering

Honors Thesis Defense


music is perpetual
and only
the hearing
is intermittent
thoreau

Abstract

- This work represents the first psychoacoustic tests of Asynchronous Interleaved Sampling (AIS) in commercial CIs
- AIS claims to improve phase representation
- Administered Schroeder phase discrimination tasks to CI users to evaluate this claim

Abstract

- Experimental trials establish that AIS does at least as well as continuous sampling
- In some cases, AIS presents an additional temporal cue
- Other consideration such as electrode spacing and parameter adjustment have potential to improve AIS further

Agenda

Sound

Cochlear Implants

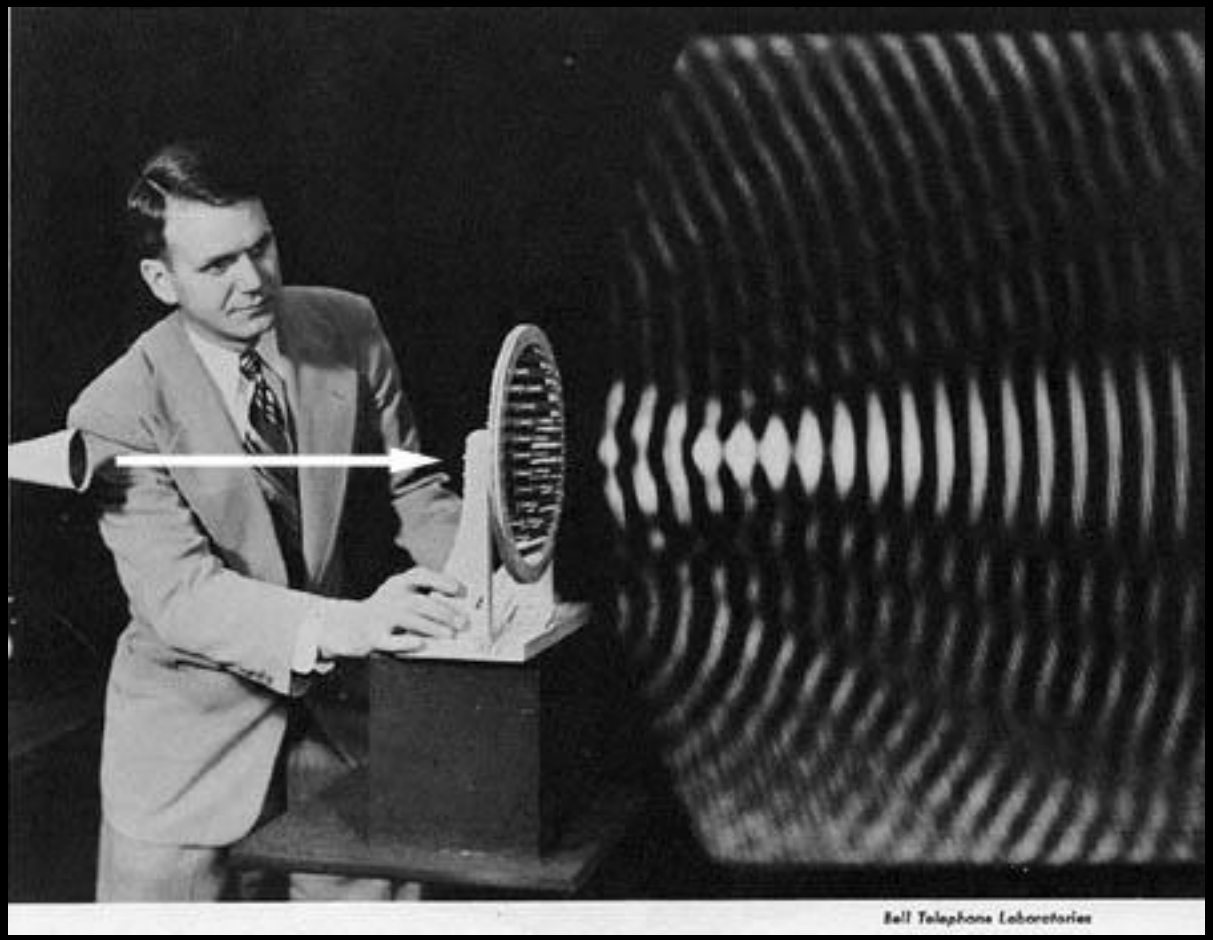
Asynchronous Stimulation

Schroeder Experiment

Results

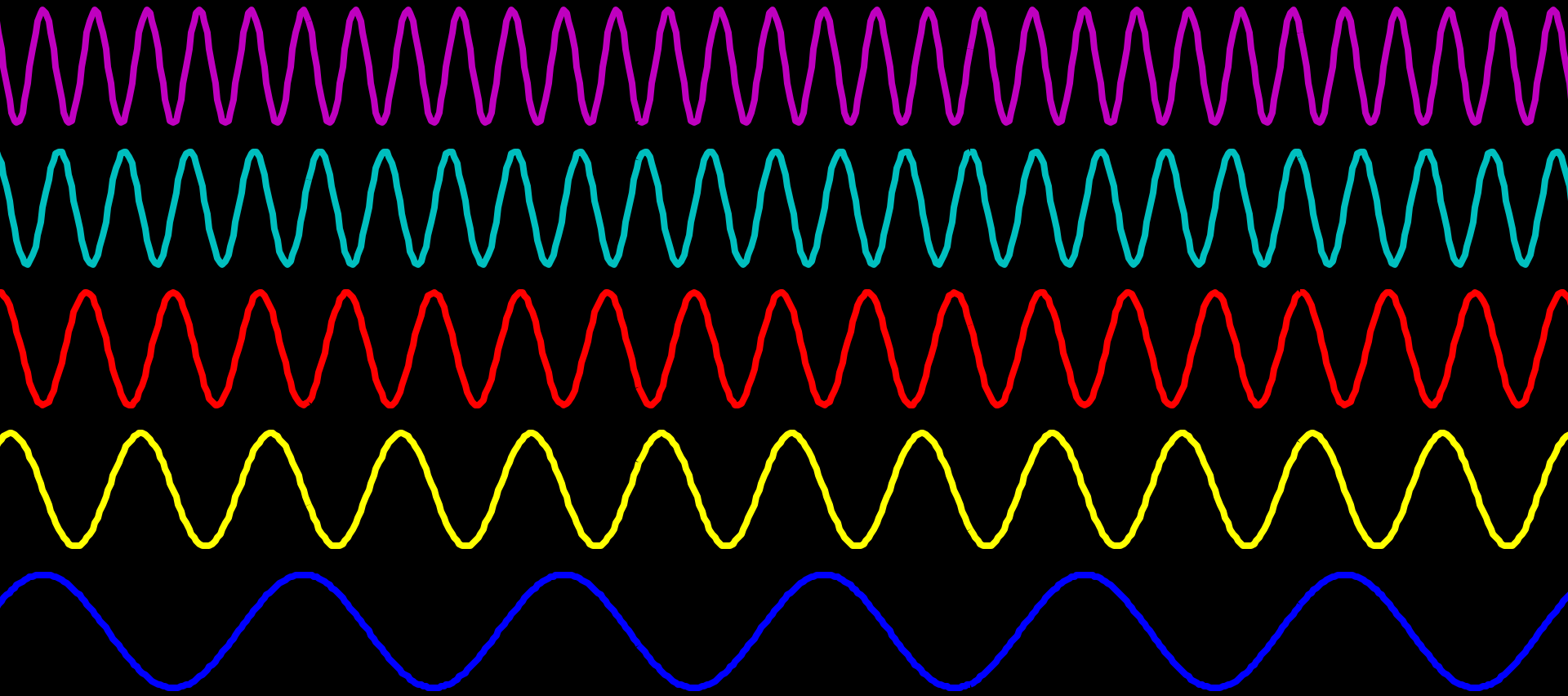
Conclusion

Sound

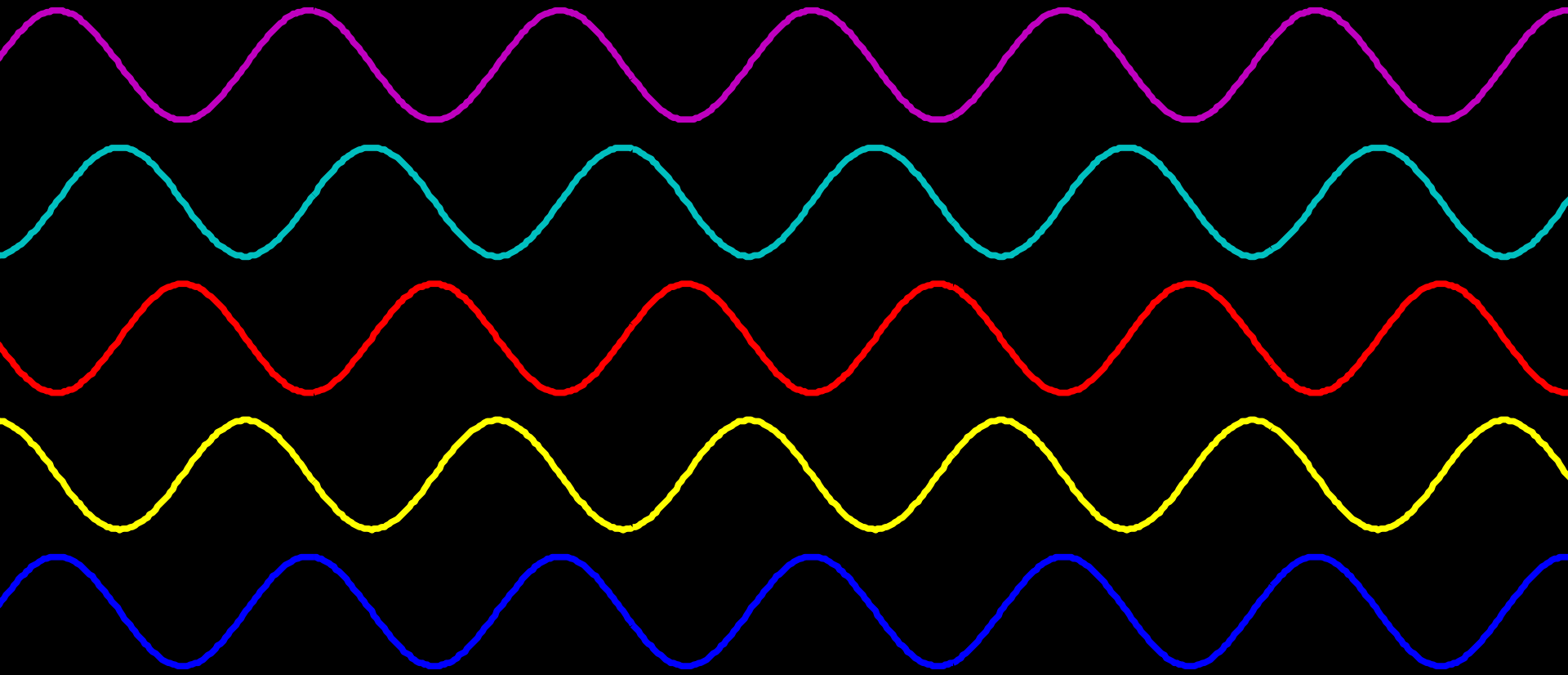


Source: David C. Knight, *The First Book of Sound: A Basic Guide to the Science of Acoustics*

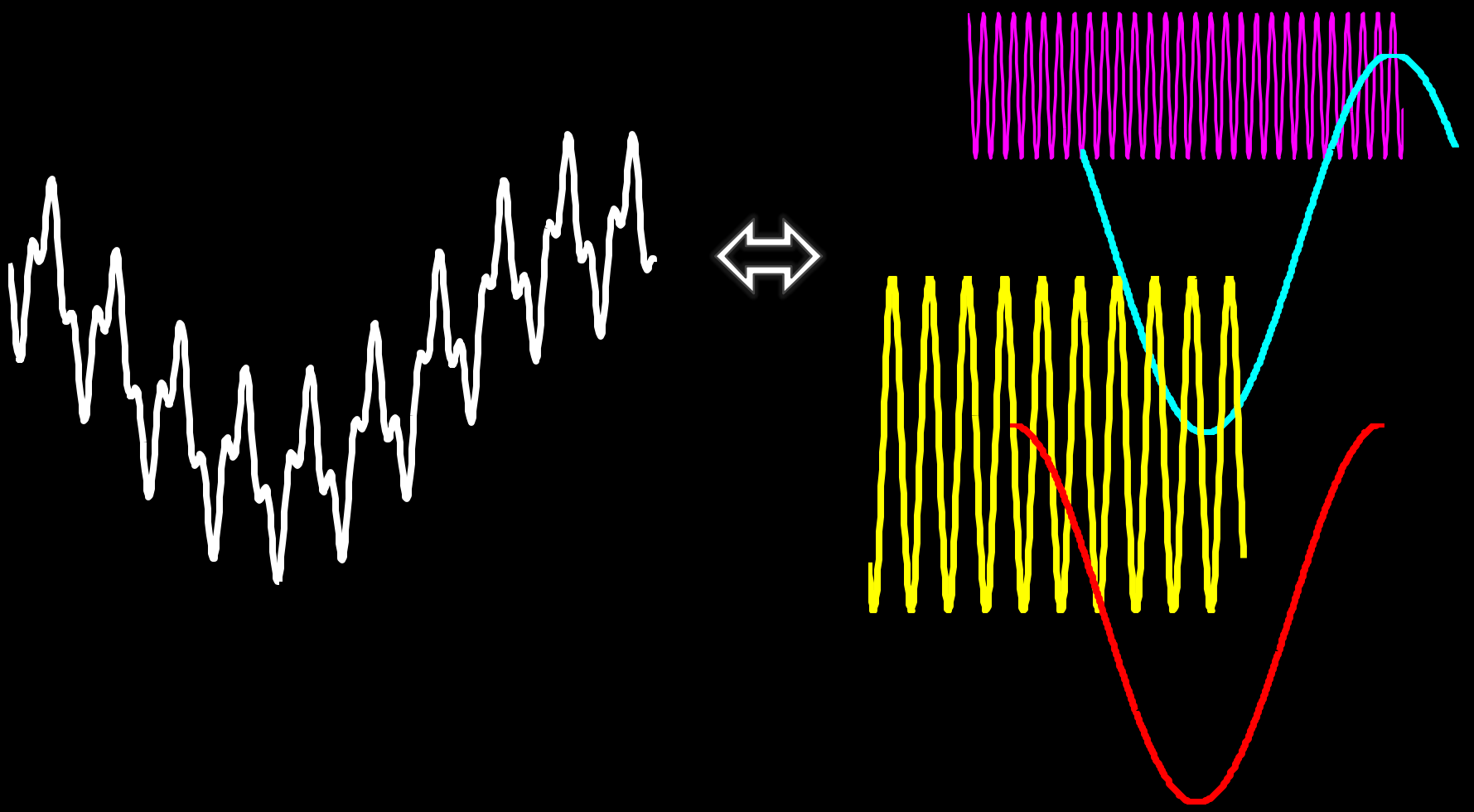
Frequency



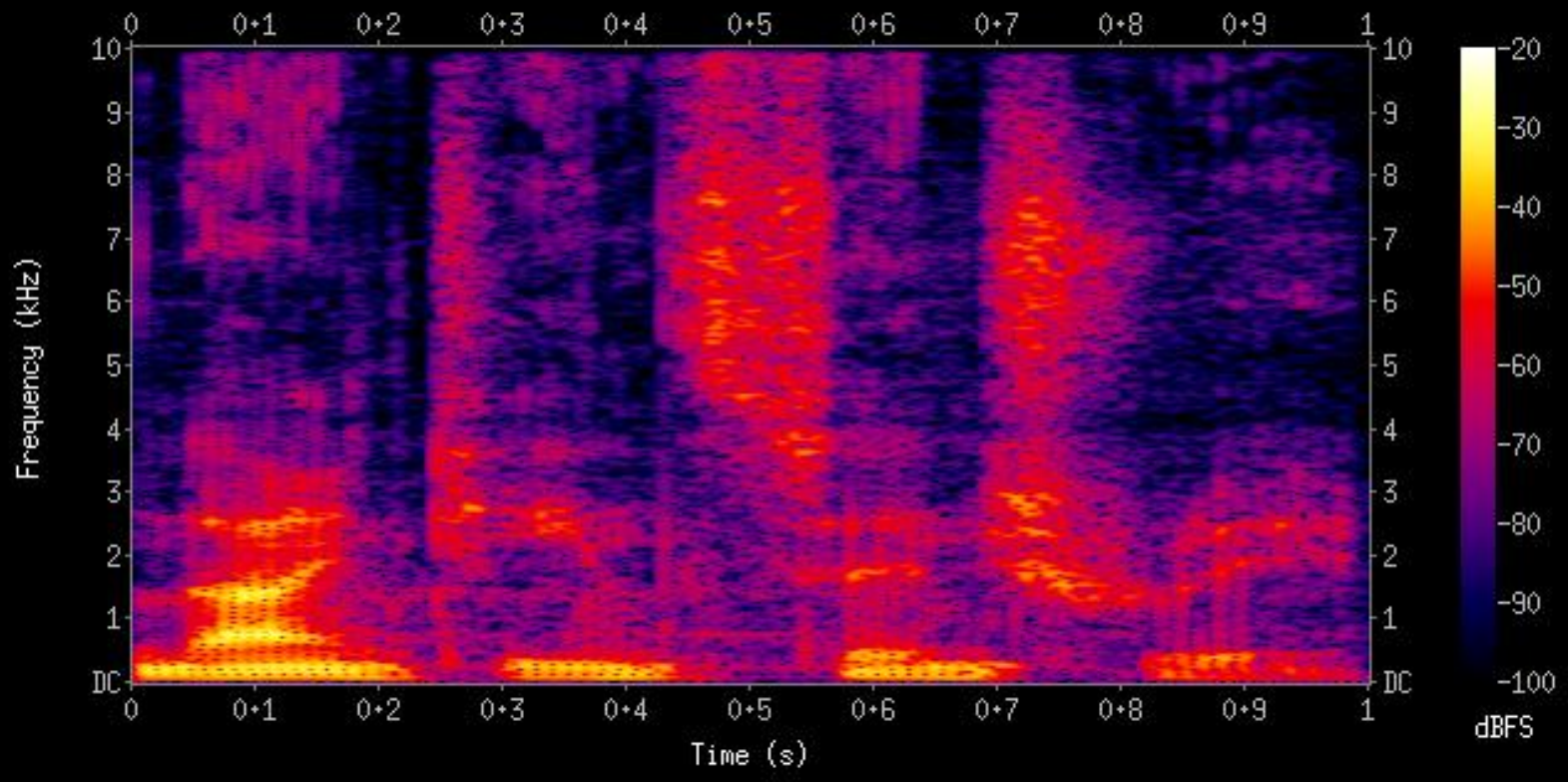
Phase



Fourier Analysis

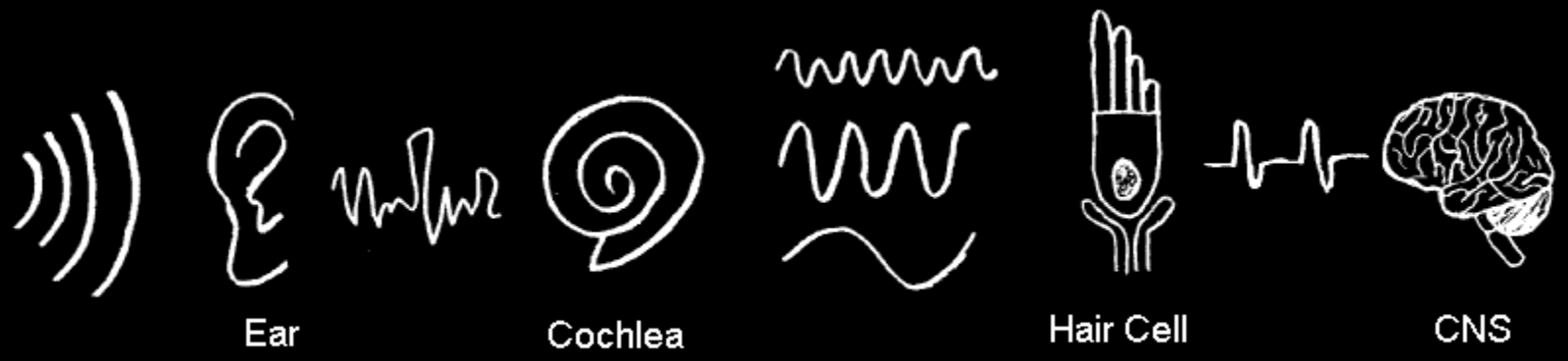


Temporal vs Spectral

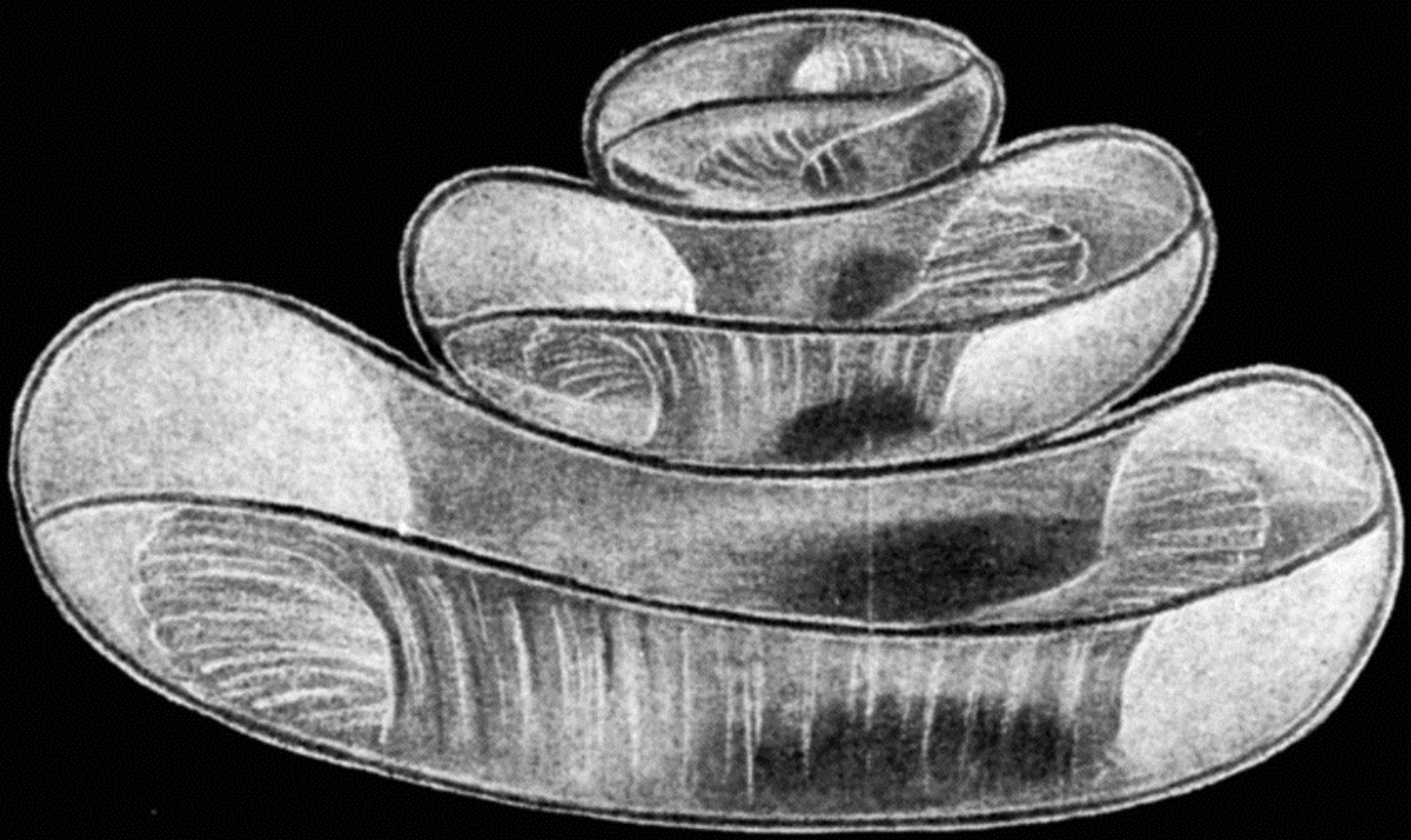


Source: Purdue University - https://www.projectrhea.org/rhea/index.php/Speech_Spectrogram

Hearing



Cochlea



Source: http://www.intropsych.com/ch04_senses/inner_ear.html

Natural Hearing

- Frequency analysis:

  Cochlea filters different frequencies along its length

- Phase tracking:

  Neurons tend to fire when stimulating wave is at its peak

Agenda

Sound

Cochlear Implants

Asynchronous Stimulation

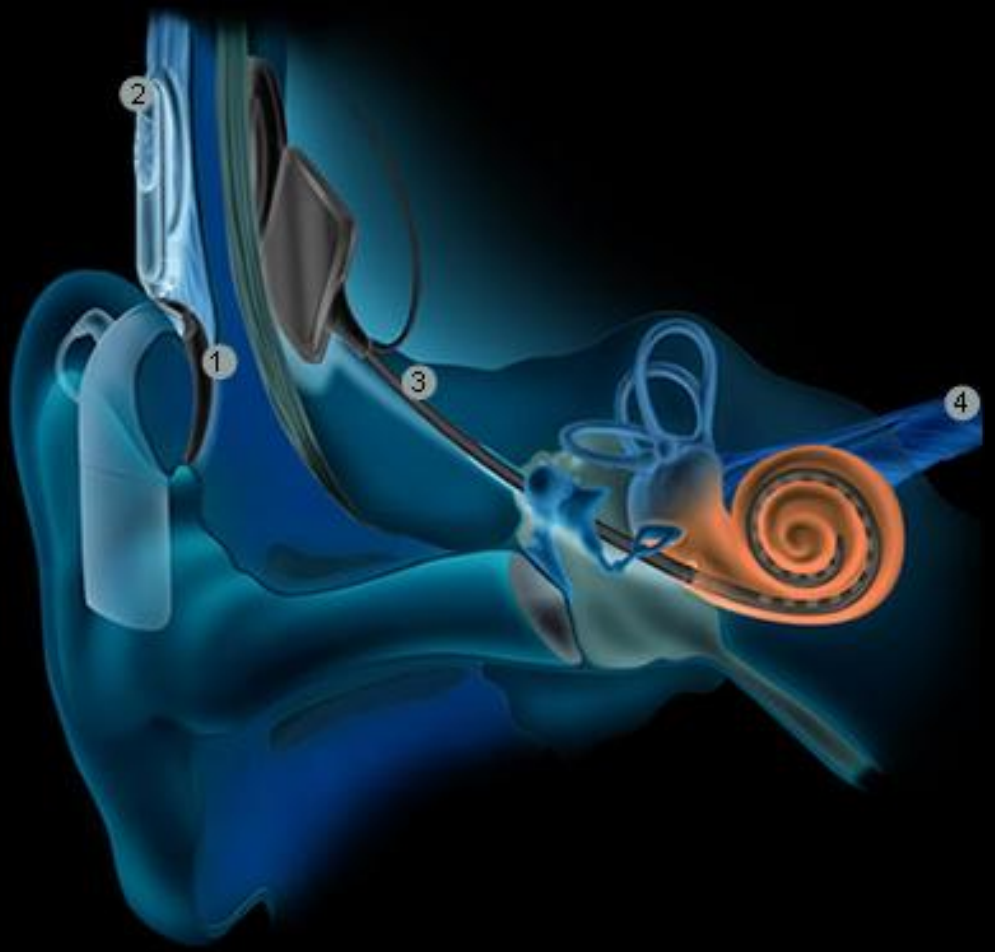
Schroeder Experiment

Results

Conclusion

Cochlear Implant

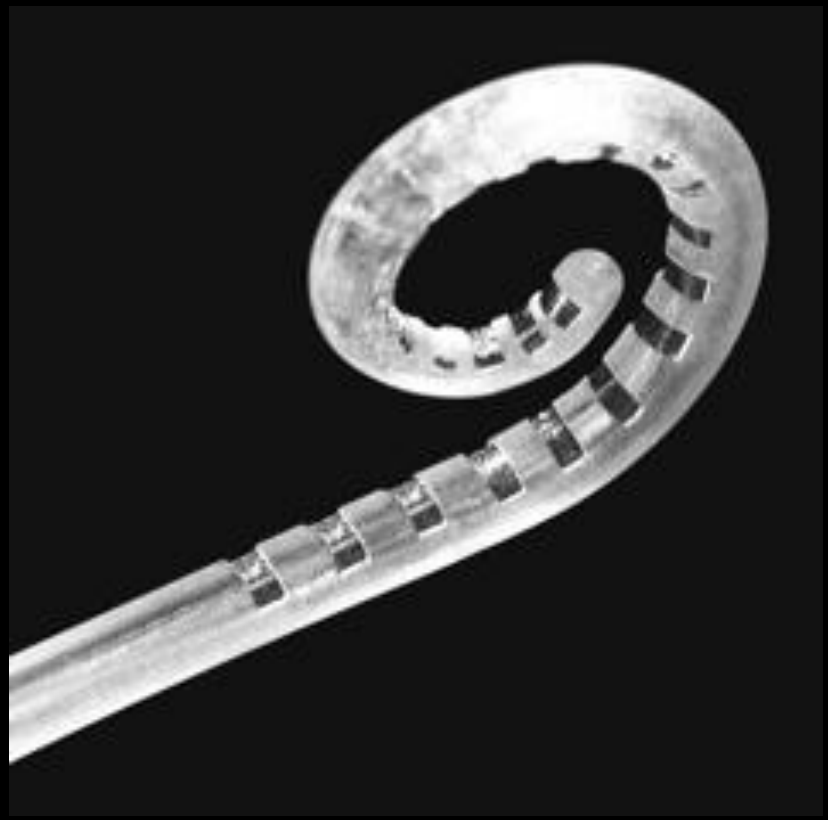
Converts sound into series of electrical pulses



Source: www.cochlear.com

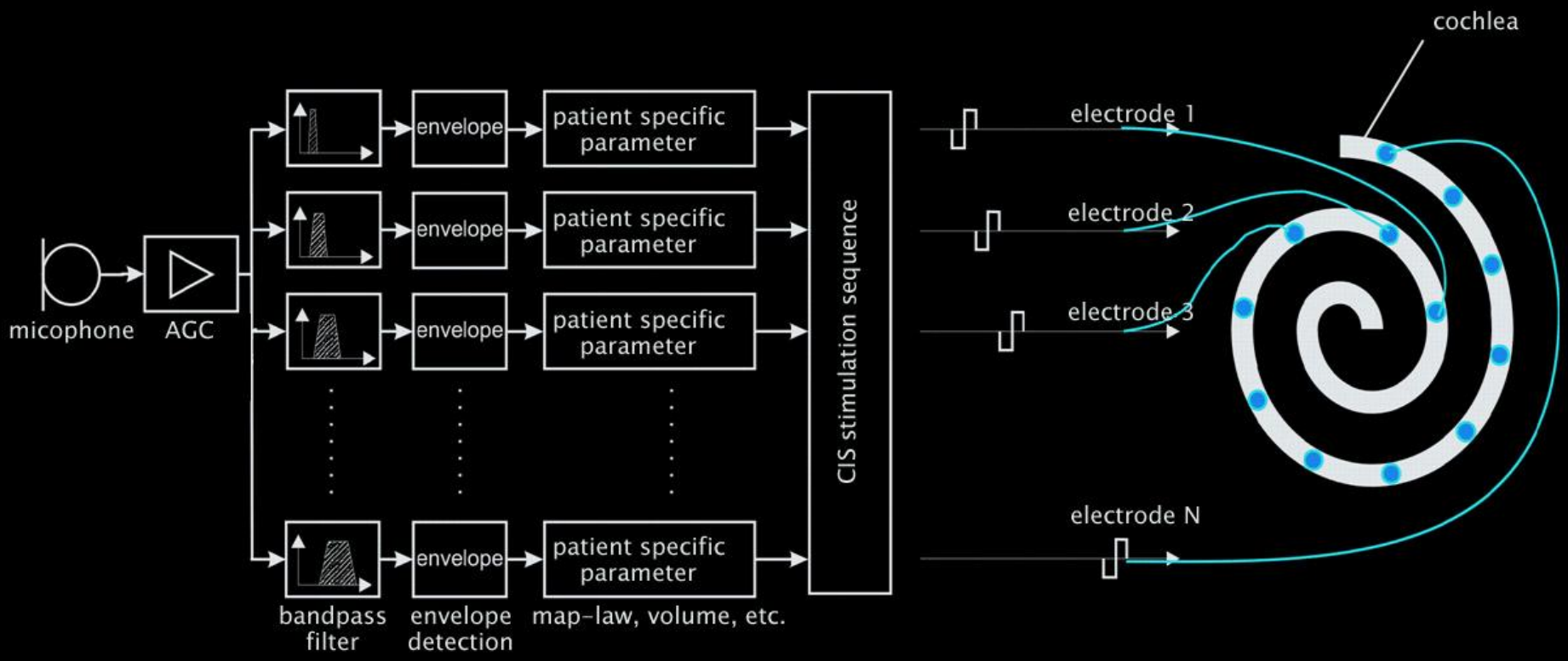
Electrode Array

- Spacing of electrodes is tight ~1.5 mm
- 22 electrodes in Cochlear brand devices
- To improve spectral resolution, no two electrodes should be activated simultaneously



Source: http://www.ssc.education.ed.ac.uk/courses/deaf/dmay11i.html

Continuous Interleaved Sampling (CIS)



Source: http://www.uibk.ac.at/activeimplants/home_en.htm

CIS Algorithm

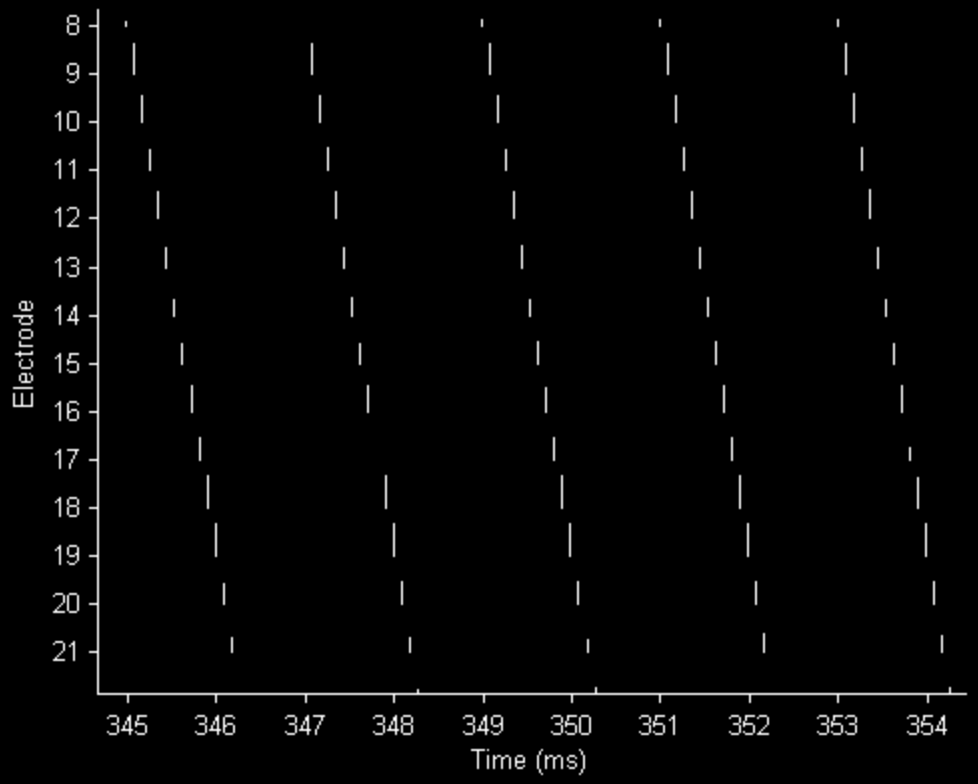
For a given analysis period:

1) Analyze sound into channels
2) Extract envelope of each channel
3) Map channel envelopes to electrode current levels
4) Deliver interleaved current pulses to electrodes

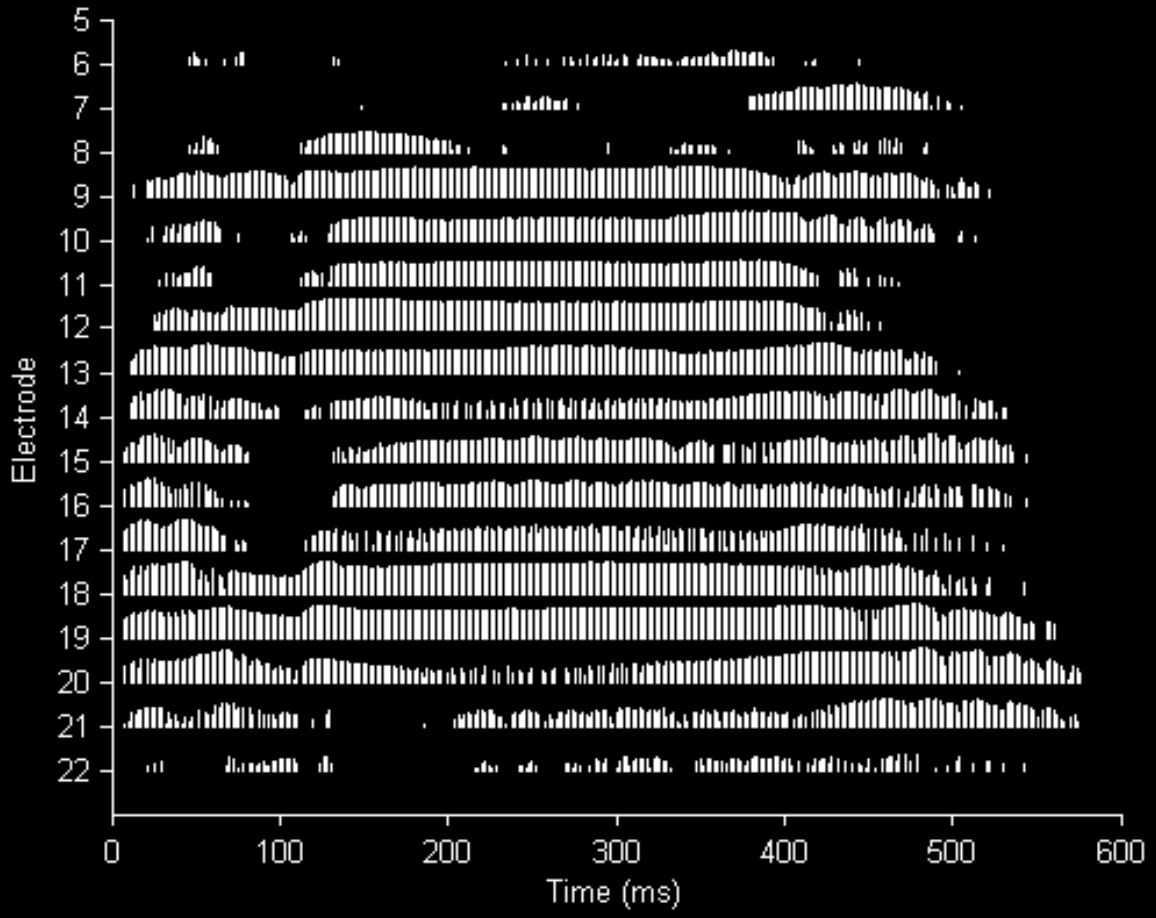
Variation: Advanced Combinational Encoder (ACE) only uses the N strongest channels

Interleaving

Stimulation happens at a constant (continuous, synchronous) rate for each channel



“Hello”


Electrode
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
0
100
200
300
400
500
600
Time (ms)

Shortfalls

- Though patients understand speech with practice, speech intonation and music is difficult
- Neurons synchronize with the meaningless CIS stimulation rate
- Continuous stimulation leads to low battery life
- Phase and temporal information is lost

Agenda

Sound

Cochlear Implants

Asynchronous Stimulation

Schroeder Experiment

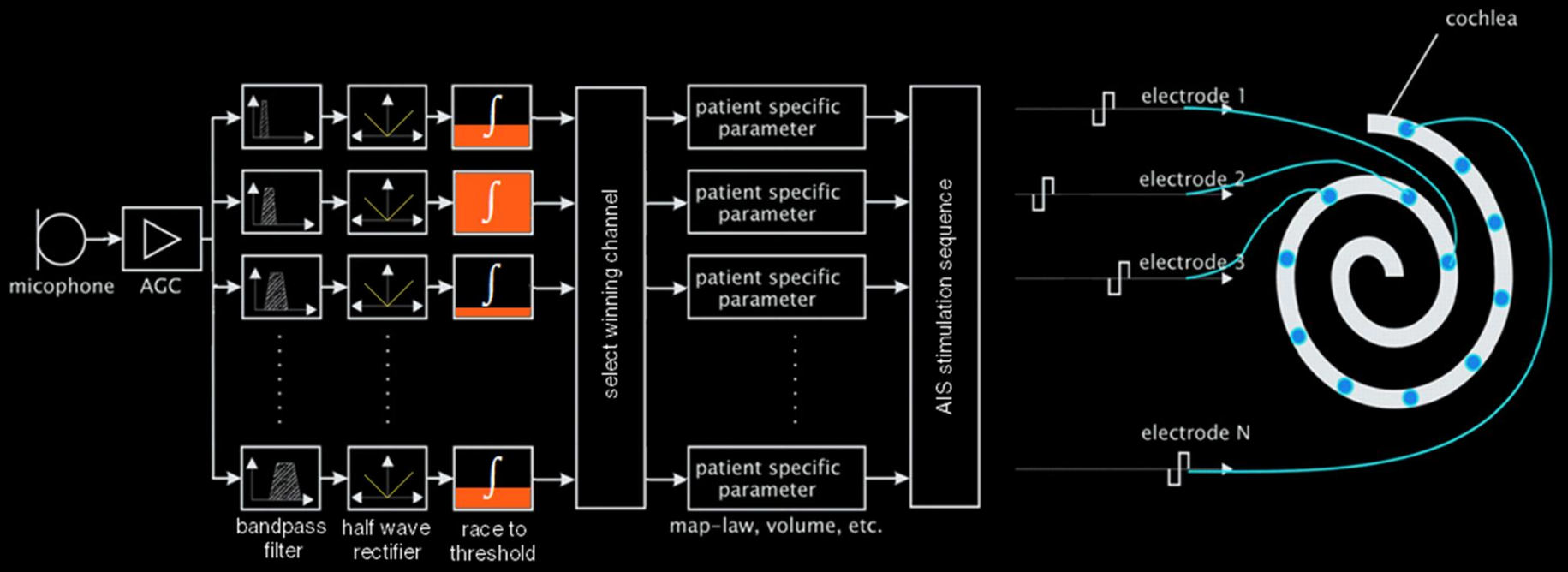
Results

Conclusion

Asynchronous Interleaved Sampling (AIS)

- Uses integrate-and-fire computation in each channel to imitate real neurons
- The “winning” channel fires, the channels are reset, and the race starts anew
- Allows for channels to adjust stimulation rate based on input
- Time between pulses now varies as necessary!

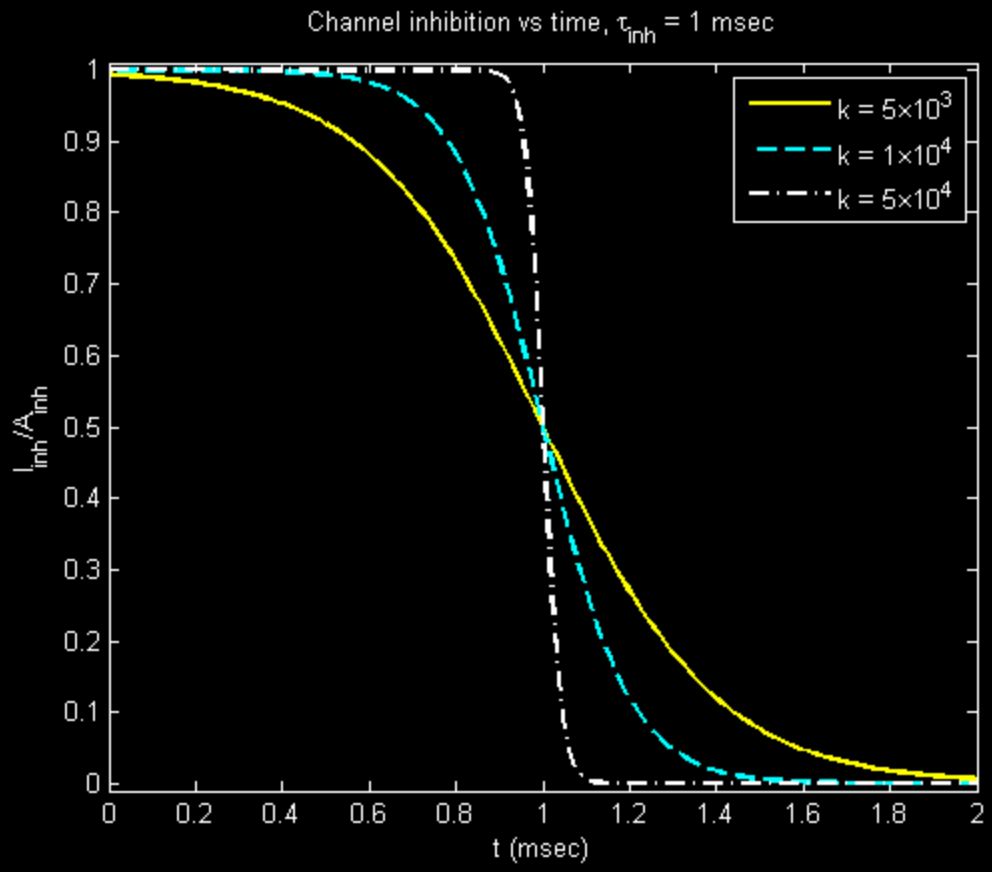
AIS


micophone
AGC
bandpass filter
half wave rectifier
race to threshold
select winning channel
patient specific parameter
patient specific parameter
patient specific parameter
patient specific parameter
map-law, volume, etc.
AIS stimulation sequence
cochlea
electrode 1
electrode 2
electrode 3
electrode N

AIS

1) Analyze sound into channels
2) Half-wave rectify channels
3) Start the race-to-fire integration
4) The first channel to reach threshold V_t delivers current pulse to its electrode
5) The “winning” channel is penalized so it cannot win again right away
6) All channels are reset and the race at 3) starts anew

Inhibition Function

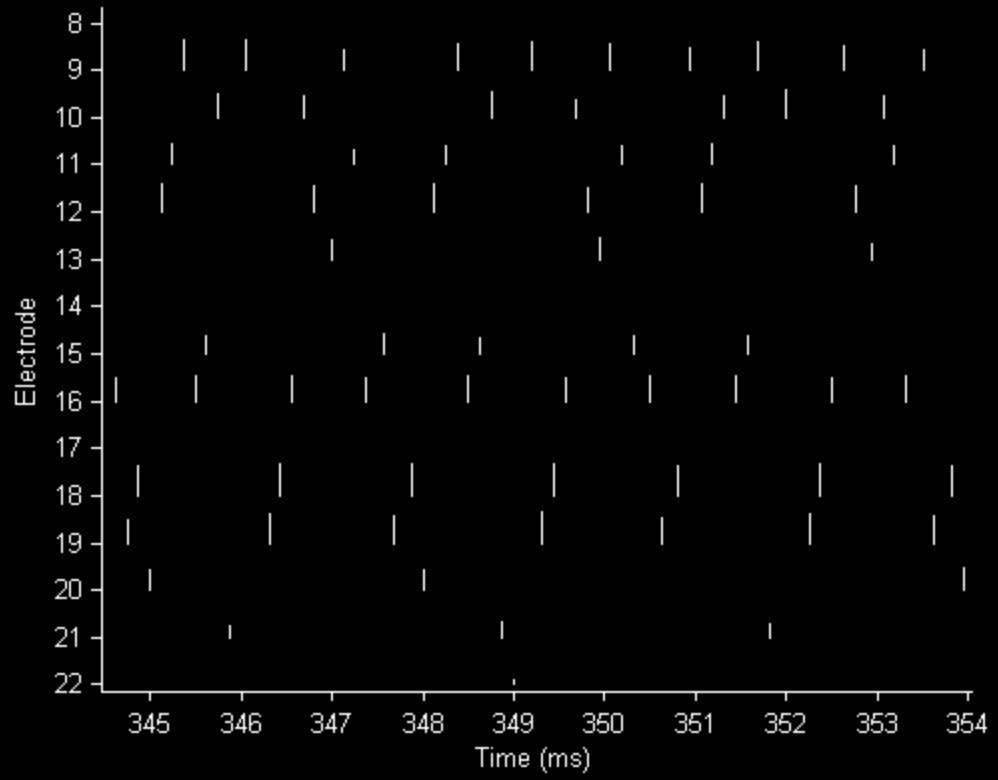


AIS Parameters

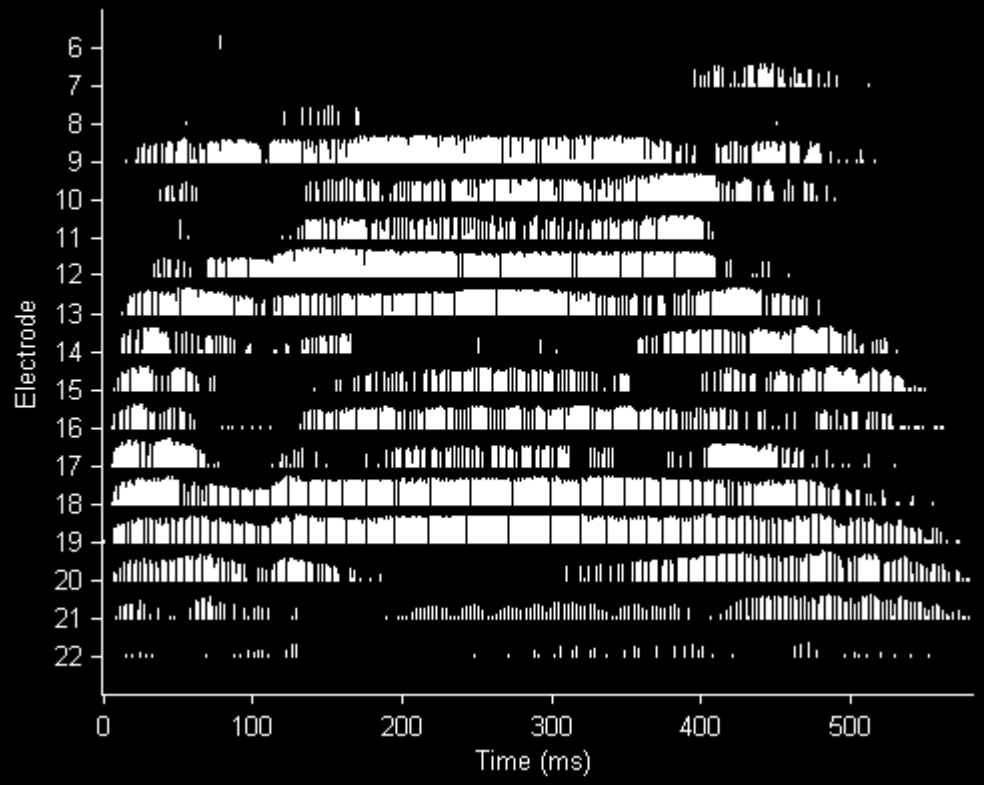
- V_t – threshold to reach before firing
  - Higher value will make it harder to spike
- τ – inhibition level half-life
  - Inhibition level rolls off to half its value in time τ

Interleaving

Ensured by only allowing the winning channel to fire at any time



“Hello”


Electrode
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
0
100
200
300
400
500
Time (ms)

Agenda

Sound

Cochlear Implants

Asynchronous Stimulation

Schroeder Experiment

Results

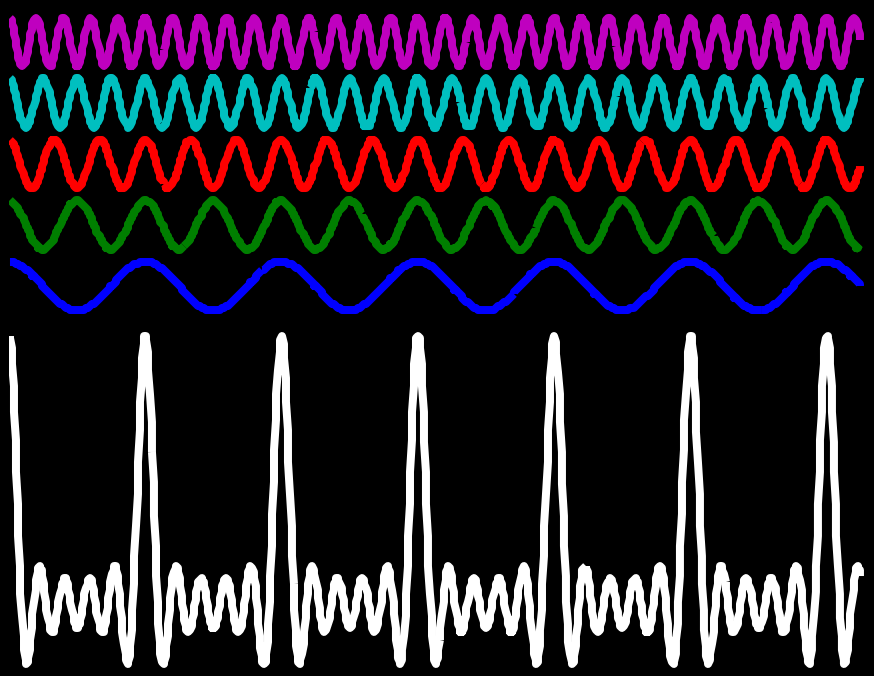
Conclusion

Ohm's Acoustic Law (1843)

- Can we hear phase?
- Ohm says "No"
- "Musical tone is perceived as a collection of harmonic tones"
- "Phase not included!"

Source: Wikimedia

Harmonic Complexes



Schroeder Phase

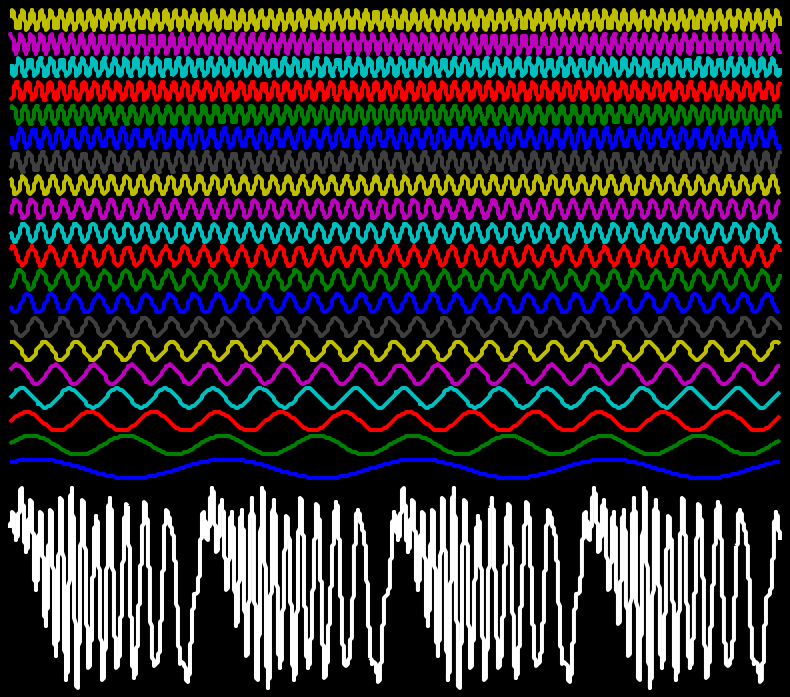
- Schroeder determined phase shift for n^{th} harmonics resulting in minimal peaks

$$\theta_n = \pm \frac{\pi n(n+1)}{N}$$

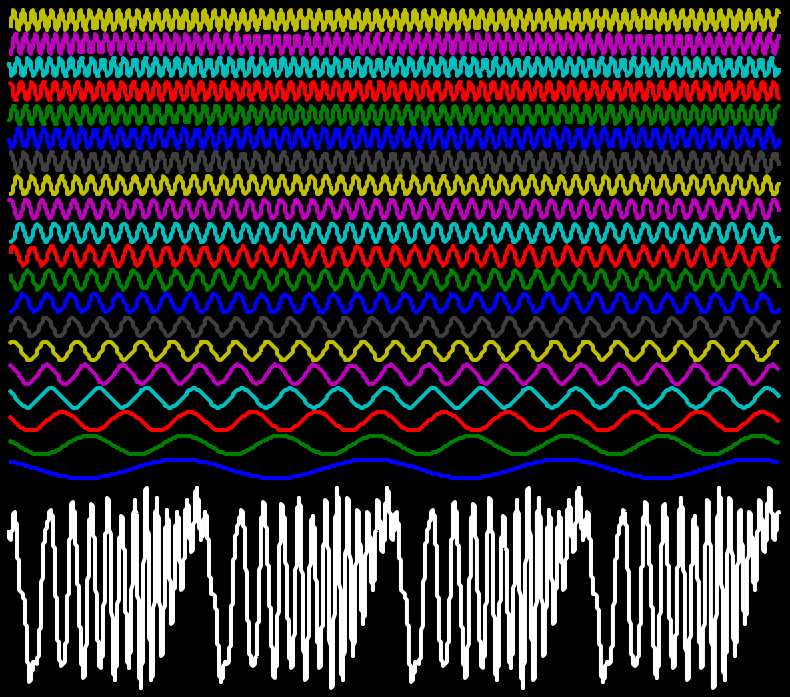
- N = total number of harmonics
- θ_n = phase for n^{th} harmonic in tone
- Changing sign of θ_n results in time-reversal

Schroeder Phase

Schr+



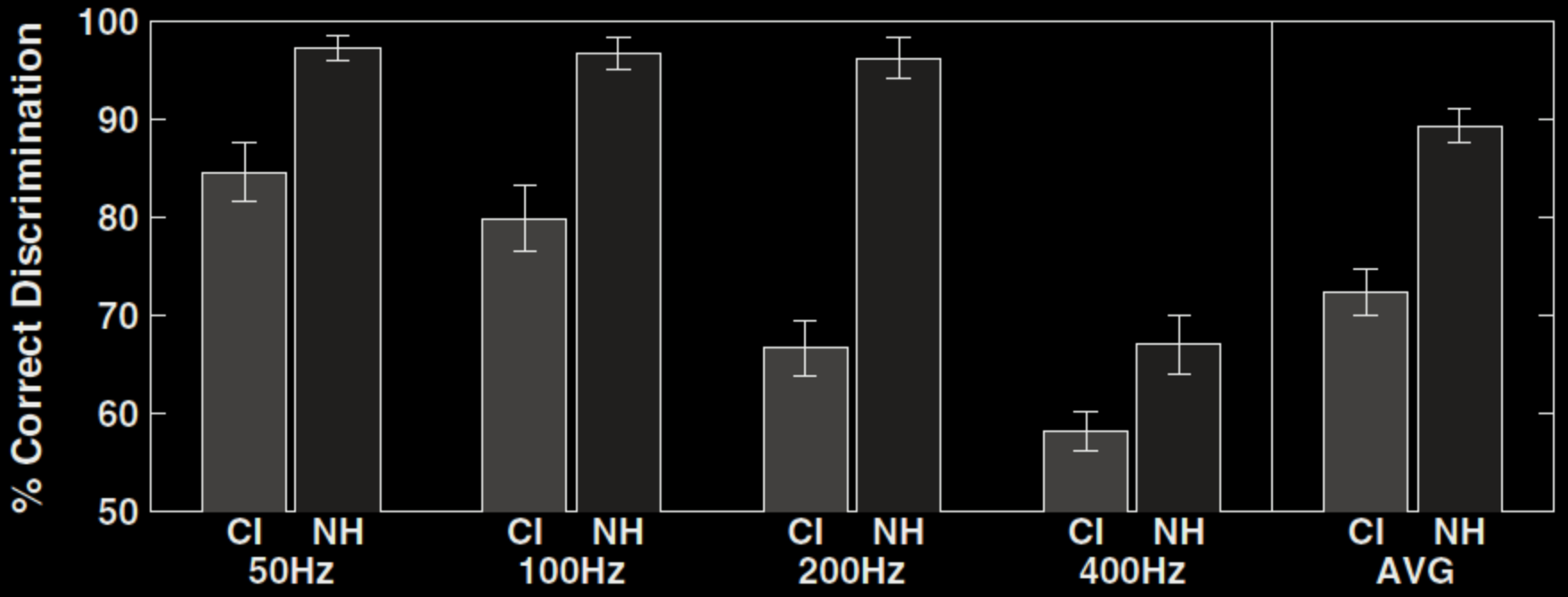
Schr-



Schroeder Phase

- Complexes have “maximally different” phase
- Exaggerated differences can be detected by normal listeners!
- The difference is purely in time domain

Phase Detection

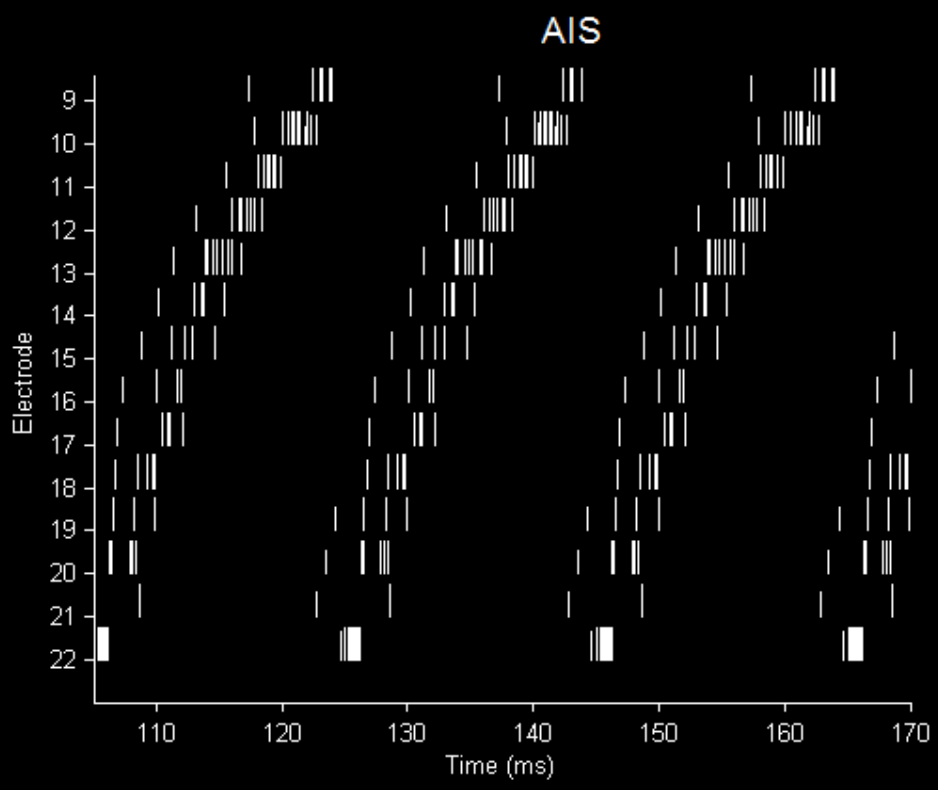


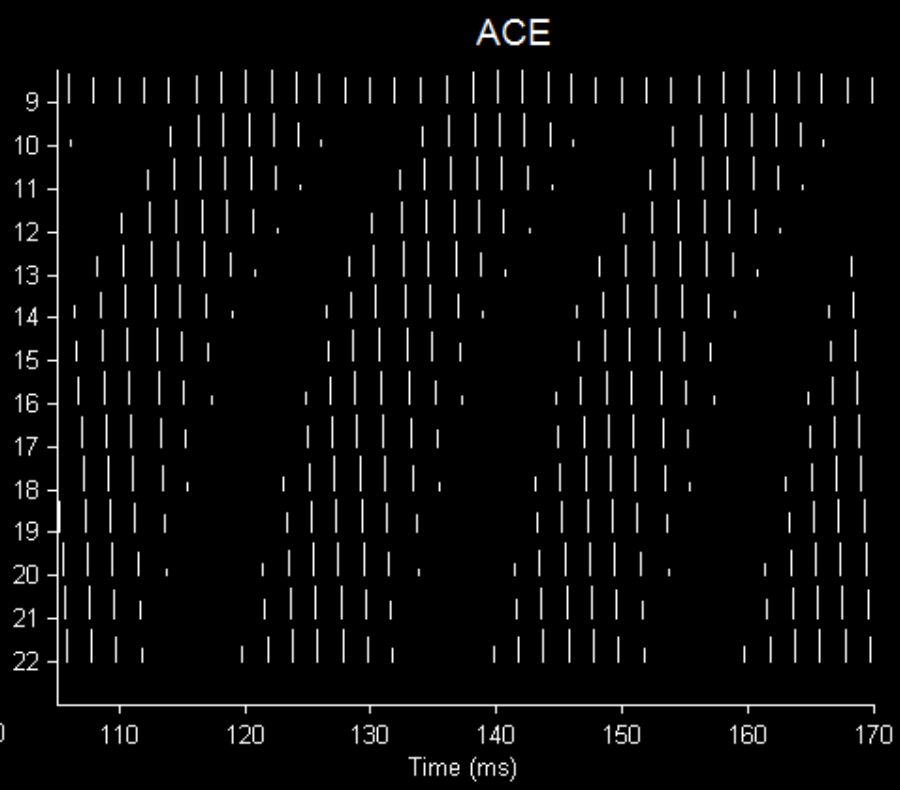
Source: Drennan et. al. (2007)

Experiment

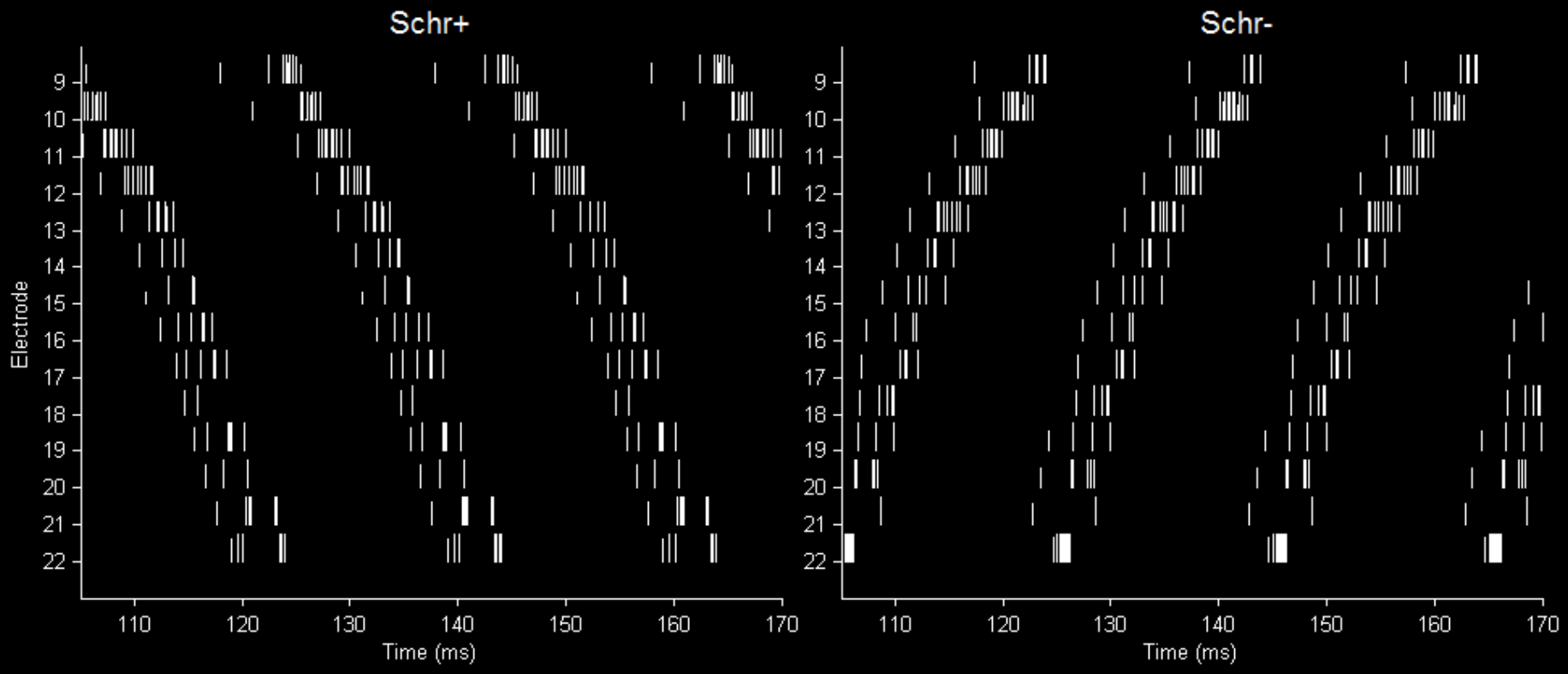
- Compare CIS vs AIS in Schroeder Phase Discrimination (SPD)
- A test of phase presentation in AIS
- Previous AIS tests used spike-based reconstructions presented to NH!

AIS vs CIS


AIS
Electrode
9
10
11
12
13
14
15
16
17
18
19
20
21
22
110
120
130
140
150
160
170
Time (ms)


ACE
9
10
11
12
13
14
15
16
17
18
19
20
21
22
110
120
130
140
150
160
170
Time (ms)

AIS SPD


Schr+
Schr-
Electrode
9
10
11
12
13
14
15
16
17
18
19
20
21
22
110
120
130
140
150
160
170
Time (ms)

Agenda

Sound

Cochlear Implants

Asynchronous Stimulation

Schroeder Experiment

Results

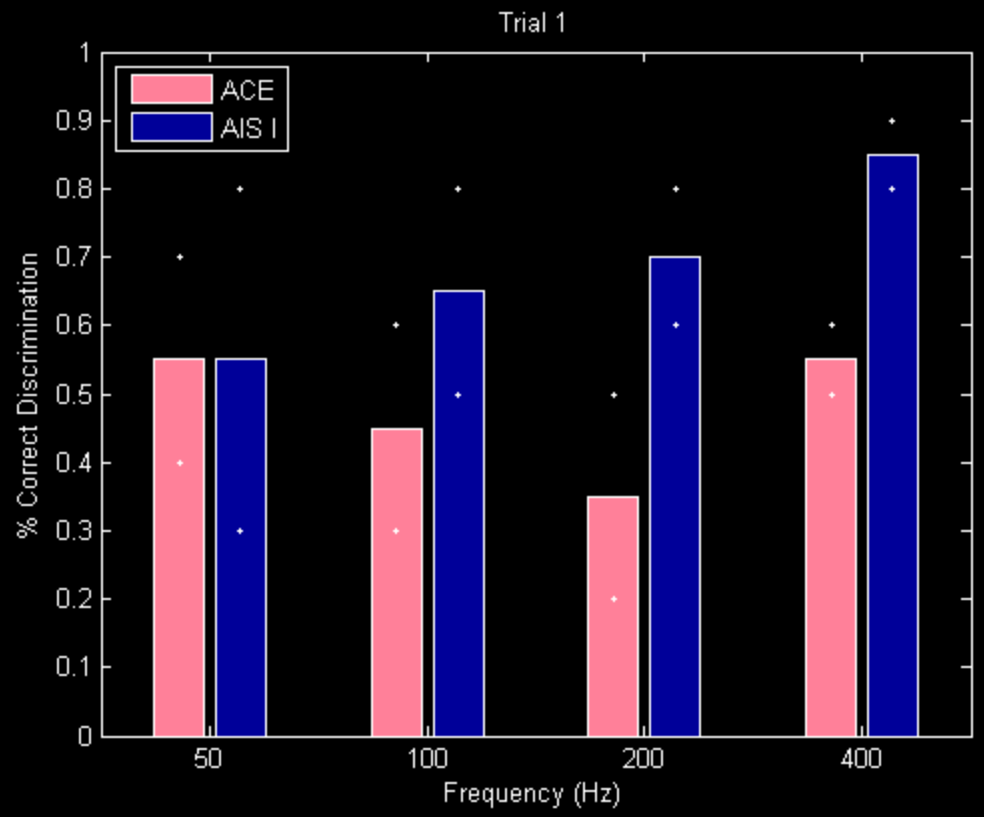
Conclusion

Trial 1

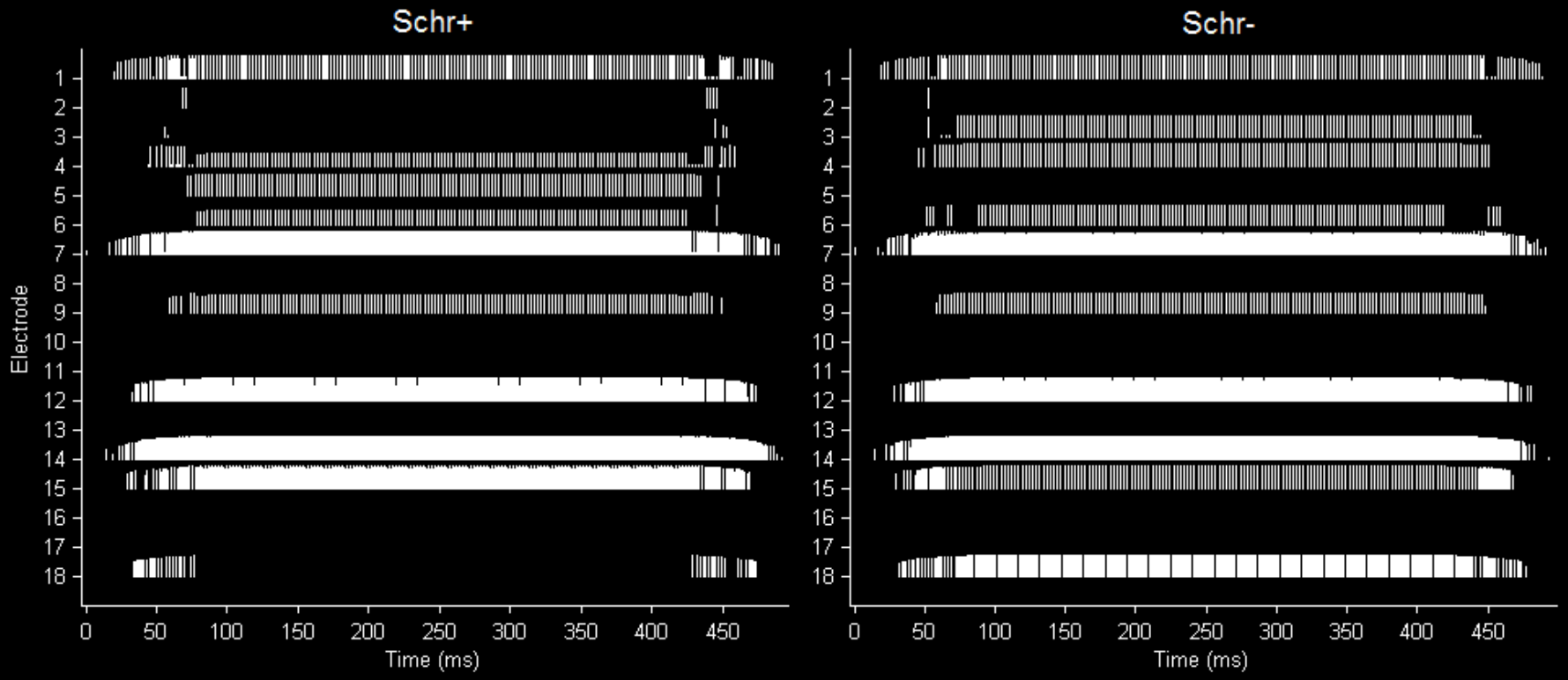
- Test SPD at 50, 100, 200, and 400 Hz

- Set parameters for fast firing rates (AIS I):
  - $\tau = 3 \times 10^{-4}$ seconds
  - $V_t = 0.35$ units

Trial 1


Trial 1
ACE
AIS I
% Correct Discrimination
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
50
100
200
400
Frequency (Hz)

Spectral Cue at 400 Hz…

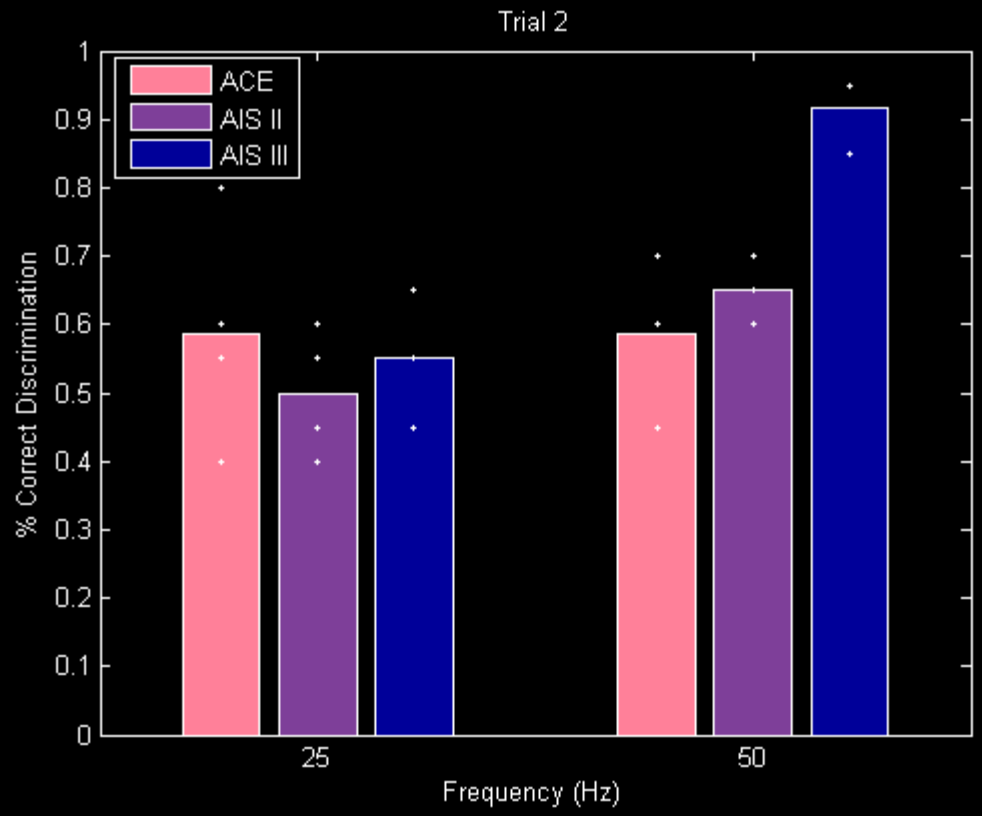


Trial 2

- Test SPD at 25 and 50 Hz
- Looking for slow, exaggerated temporal patterns

- Extended refractory period (AIS II)
  - $\tau = 5 \times 10^{-5}$ seconds
  - $V_t = 0.075$ units
- More difficult to spike (AIS III)
  - $\tau = 3 \times 10^{-4}$ seconds
  - $V_t = 2.0$ units

Trial 2


Trial 2
ACE
AIS II
AIS III
% Correct Discrimination
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
25
50
Frequency (Hz)

Trial 2

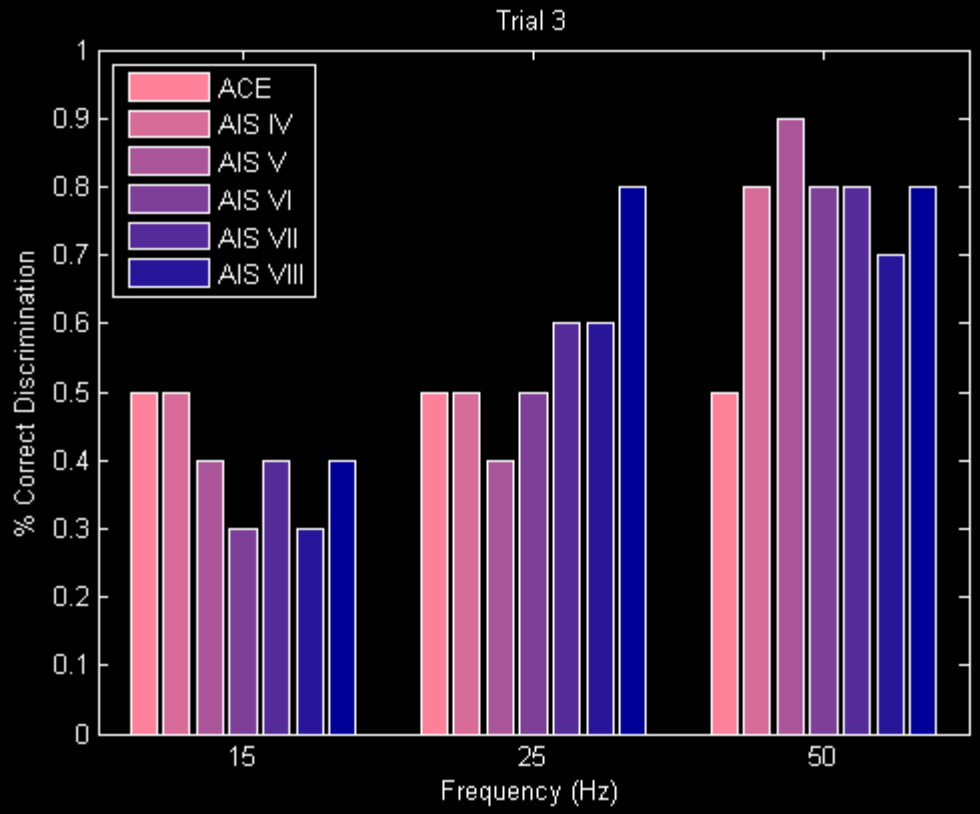
- Subject was able to identify temporal cue!
  - Detected 10 ms ramp window of the function
  - The gross phase structure of signal was not detected
- No major difference between AIS and CIS in presenting main structure of tone

Trial 3

- SPD at 15, 25, and 50 Hz
- Potpourri of parameters selected
  - V_t and τ adjusted various ways
- Shorter sessions (1/2 number of trials)

- No significant difference from CIS

Trial 3


Trial 3
ACE
AIS IV
AIS V
AIS VI
AIS VII
AIS VIII
% Correct Discrimination
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
15
25
50
Frequency (Hz)

Results

- AIS presents a temporal cue (the ramp) that CIS cannot
- Perception overall does not differ dramatically between the two processing strategies…

- Why is this?

Agenda

Sound

Cochlear Implants

Asynchronous Stimulation

Schroeder Experiment

Results

Conclusion

Conclusions

- Window analysis size may be more critical
  - Spectral/temporal resolution tradeoff
  - AIS automatically readjusts window for every frequency
- Finer temporal “shape” may not be detectable by CI users, but **some** temporal cue is
- Could use more harmonics in tone structures (Drennan et al.)

Conclusions

- No significant benefit of AIS over ACE in Schr phase perception

- Experiment can be modified:
  - Changing Electrode spacing (turning off every other channel emphasizes separation)
  - Using more harmonics in Schr tones

Future Work

- Adjust AIS to a “winner-take-some”
  - Allow two or three winners each “race”
  - Prevents weak channels from being totally suppressed by stronger ones
  - CIS/AIS hybrid
- Re-administer Schr phase test
  - Adjust electrode separation
  - Use more harmonics

Future Work

- Study basilar wave propagation
  - Low frequencies travel further, larger prop. delay
- Study processing of OFDM signals to understand how Schr tones may be processed
  - High PAPR signals cause problems
  - Schr are low PAPR signals
- Go beyond Fourier… experiment with other orthonormal basis functions to model hearing

Thanks!

Bomjun Kwon
Steven Bibyk
Hooshang Hemami
Jae Park
Trevor Perry
Cassie Wilhelm

…and You! ☺